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A Study of

DIURNAL VARIATIONS IN BLOOD PRESSURE

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BRENTON REID LUTZ
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INTRODUCTION

The determination of arterial blood pressure by means of the sphygmomanometer has been so generally adopted during the last few years in practical medicine, in the clinic, in the laboratory, in life insurance examinations, in fact, wherever a physical examination is necessary, that an accurate knowledge of the normal variations in pressure during the day is needed in order that the determinations may be of practical value. Investigators have recognized that normal variations in arterial blood pressure take place, for example, after meals, during and after exercise, in various emotional states, and under other physiological and psychological conditions. No conclusive investigation has been made to show the constant normal variations in blood pressure that occur during the day. In fact, only recently has a convenient and accurate method been perfected, the auscultatory method, which enables this work to be done.

The chief aim of this thesis is to present the results of a systematic study of the diurnal blood pressure variations in young healthy adults. But in order to make the paper of interest to the general reader Part 1 has been devoted to a description of the general physiological anatomy of the heart and blood vessels, to a few remarks concerning the physiology of the circulatory system, and to a discussion of the main features of arterial blood pressure.

PART 1

The Anatomy and Physiology of the Circulatory System.

Anatomy

General statement. During life the process of metabolism is carried on in each organ and tissue of the body. This process is characterized by the assimilation of food materials and the production of waste; and for its maintenance it is necessary that there shall be a constant supply of the former, and a constant removal of the latter. The blood serves this purpose by continually flowing through the tissues with a volume, pressure, and velocity depending upon their activity.

The apparatus which maintains the circulation consists of a central organ, the heart; a series of branching distributing tubes, the arteries; a network of thin walled microscopic tubes, the capillaries; and a series of collecting tubes, the veins. These structures form a closed system within which the blood is kept in motion in one direction, mainly by the pumping action of the heart, the action of the valves, and the elasticity of the arteries.

The heart. The heart is a hollow, muscular, cone-shaped organ lying in the chest just behind the sternum. Its broader end, or base is turned upwards and projects to the right of the sternum; while the apex projects to the left, extending downward as far as the fifth intercostal space. Enclosing and suspending the heart is a thin sac-like membrane, the pericardium. Between the pericardium and the heart a small

quantity of fluid moistens the contiguous surfaces, diminishing the friction.

The heart is completely separated into right and left parts by a vertical septum, each of which is partly subdivided by a transverse constriction into two chambers, an upper thin walled cavity, the auricle, and a lower thick walled chamber, the ventricle. Of the four cavities, the right auricle and ventricle constitute the venous heart; while the left auricle and ventricle make up the arterial heart.

The right auricle shows on its posterior aspect the terminals of the two final trunks of the venous system. the superior and inferior venae cavae. It communicates with the ventricle by means of the auriculo-ventricular orifice. The wall of this auricle is relatively thin.

The right ventricle presents on its upper left angle a prolongation, the conus arteriosus, from which arises the pulmonary artery, the orifice of which is guarded by semi-lunar valves to prevent the return of the blood into the ventricle. The wall of this ventricle is about twice as thick as that of the right auricle. Its inner surface presents a system of muscular projections, the musculi papillares, which point upward toward the auriculo-ventricular opening. From the apex of each papillary muscle fine tendinous cords are given off which support the auriculo-ventricular or tricuspid valve which prevents the return of blood into the right auricle.

The left auricle presents on its posterior surface the termination of the four final trunks of the venous system of the lungs, the pulmonary veins. It communicates with the left ventricle by means of an opening similar to the right auriculo-ventricular orifice. The wall of this chamber is thicker than that of the right auricle, but not so thick as that of the right ventricle.

The left ventricle presents on its upper right angle the main arterial trunk of the systemic circulation, the aorta, the orifice of which is guarded by semi-lunar valves to prevent the return of blood into the ventricle. The inner surface shows a system of columnae carneae, musculi papillares, and chordae tendineae much better developed than those of the right ventricle; and the wall is about three times as thick as that of the latter. The bicuspid or mitral valve prevents the return of blood into the left auricle.

In the auricles the muscle bundles are arranged in two sets, an outer transverse set which passes from auricle to auricle, and an inner longitudinal set which passes over the auricles and attaches on the anterior and posterior surfaces at the auriculo-ventricular groove. Circularly arranged fibres are present near the venae cavae and pulmonary veins. In the ventricles the muscle bundles are arranged in two sets, an outer longitudinal and an inner transverse set. The longitudinal fibres, in general, begin at the auriculo-ventricular groove on the anterior

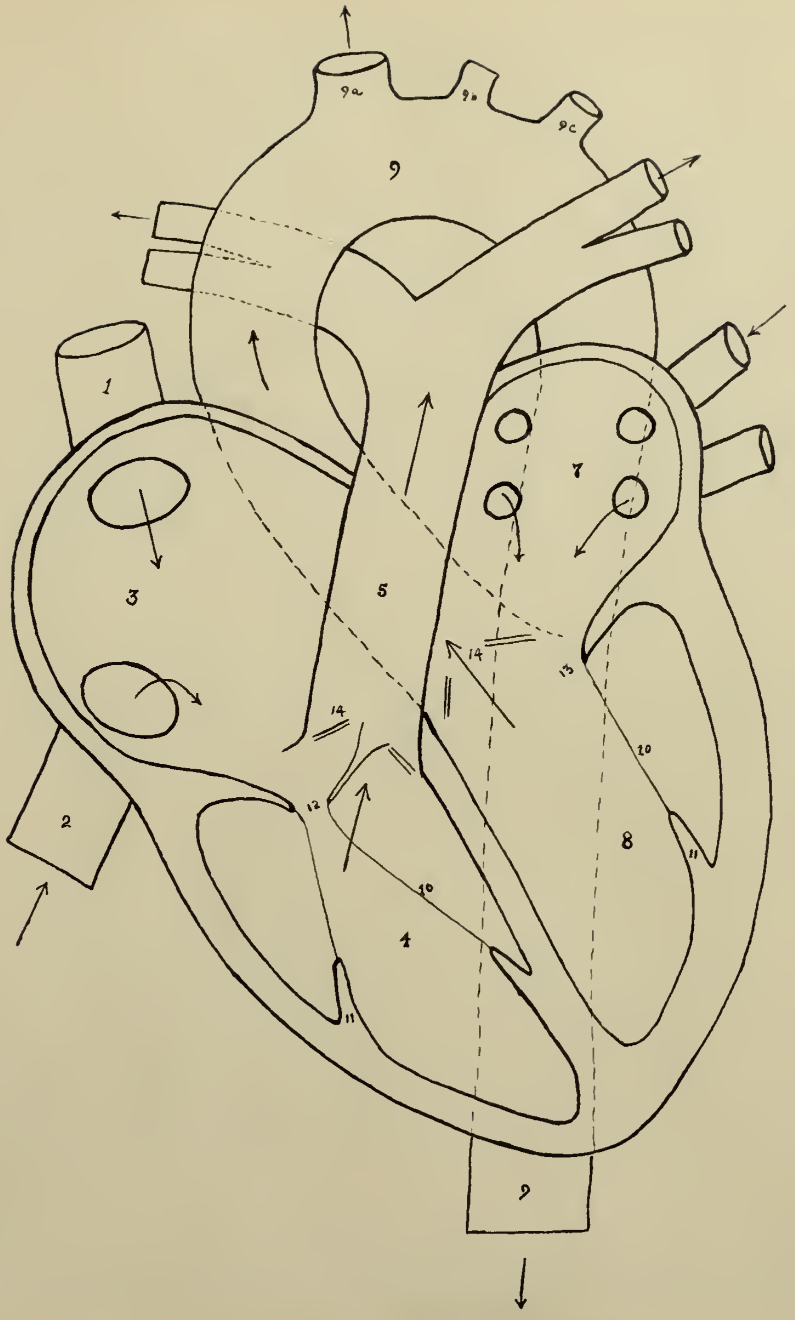

Fig. 1. Diagram of the course of the blood through the heart. 1, 2. Superior and inferior venae cavae. 3. Right auricle. 4. Right ventricle. 5. Pulmonary artery. 6. Pulmonary veins. 7. Left auricle. 8. Left ventricle. 9. Aorta. 9a. Innominate artery. 9b. Left carotid artery. 9c. Left subclavian artery. 10, 10. Chordae tendineae. 11, 11. Musculi papillaris. 12. Tricuspid valve. 13. Mitral valve. 14, 14. Semi-lunar valves. (After Morat and Doyon) From Brubaker.

and posterior surfaces, and pass downward obliquely toward the apex, where they turn backward and inward in a vortex, and then ascend to terminate in the wall of the interventricular septum, the columnae carneae, and the musculi papillares. Some longitudinal fibres are found on the inner surface. The transverse fibres are very abundant, and surround each ventricle separately. There are also other minor layers passing in various directions. The arrangement of the heart muscles is such as to insure a simultaneous contraction of both auricles, followed by a simultaneous contraction of both ventricles.

The blood vessels. Most of the arteries arise from the aorta although some take their origin from the pulmonary artery. This latter vessel carries venous blood to the lungs where it exchanges gases with the air, giving off carbon dioxide, and taking in oxygen.

The aorta, as it leaves the heart, turns downward upon itself forming an arch, after which it continues through the thoracic cavity giving off branches on its way. It pierces the diaphragm and enters the abdomen, where, after supplying that region, it ends opposite the last lumbar vertebra by dividing into right and left common iliac arteries, which supply the lower limbs. Anatomists, when describing this main vessel speak of the arch, the thoracic aorta, and the abdominal aorta.

From the arch of the aorta there first arise the coronary arteries, which supply the heart. Then three large branches are given off, of which the first is the innominate artery, which immediately divides into the right subclavian and the right

common carotid-arteries, the second, the left common carotid, and the third, the left subclavian. Each subclavian artery passes outward to the arm on its respective side, and after giving off a vertebral artery crosses the axilla and runs down the front of the arm as the brachial artery, giving off branches all the way. Just below the elbow it divides into the radial and ulnar arteries which supply the forearm, hand, and fingers.

The common carotid arteries pass upward along the trachea. At the level of the jaw each divides into an internal and external carotid. The external branch supplies the face, scalp, and salivary glands. Its main trunk, the temporal artery, is situated so near the surface that frequently its pulsations may be seen. The internal carotid artery enters the cranium at the base of the skull, and with the vertebral arteries supplies the brain.

The thoracic aorta gives off the intercostal arteries which supply the chest walls, and the bronchial arteries which supply the lung tissue.

Since many of the important organs are situated in the abdomen, the aorta gives off numerous branches in this region. Among the most important are the coeliac axis which supplies the stomach, spleen, liver, and pancreas; the superior mesenteric which supplies the greater part of the intestine; the renal arteries which supply each kidney; and the inferior mesenteric which passes to the remaining portion of the intestine.

Each common iliac artery divides into an internal and an external branch. The internal iliac supplies the parts situated in the pelvis. The external iliac proceeds down the inside of the thigh as the femoral, then passes behind the femur. In the region of the knee joint it becomes the popliteal, which divides into the anterior and posterior tibial arteries supplying the leg and foot.

As the arteries become remote from the heart their branches become smaller and smaller, until the smallest arterioles become continuous with the capillaries which form an exceedingly fine network in nearly all parts of the body. The walls of these delicate tubes are very simple consisting of a single layer of endothelial cells, permitting a supply of nutritive material to pass through to the cells of the surrounding tissues.

The beginnings of the veins, like the terminations of the arteries are very small. They arise from the capillaries and by their convergence and union gradually increase in size in passing from the periphery toward the heart. Finally they consist of two large trunks, the inferior and superior venae cavae.

By means of the blood vascular system all the blood that leaves the heart by the aorta, except that flowing into the coronary arteries which supply the heart itself, is distributed to the tissues and finally collected into the large venous trunks and poured into the right auricle. From the right auricle it passes into the right ventricle, and then by way of the pulmonary artery is carried to the lungs and passes through a network of capillaries where an exchange of gases takes place. The arterial

blood passes from the lungs by way of the pulmonary vein to the left auricle, from which it is forced into the left ventricle. The muscular walls of the left ventricle throw the blood into the aorta with an energy sufficient, when aided by other factors, to maintain the circulation.

The Physiology of the Circulatory System.

The heart. The direct cause for the movement of the blood through the vessels is the contraction and relaxation of the muscular walls of the heart; and with the aid of the valves the flow is maintained in one direction. The contraction of any part of the heart, termed systole, transforms the potential energy stored up during the period of rest, termed diastole, into kinetic energy. The whole heart, however, does not contract at one time. It presents two distinct successive contractions, the first, short and quick, auricular systole, by which the blood is forced from the auricles into the ventricles; and the second longer in duration and more vigorous, ventricular systole, by which the blood is forced from the ventricles into the pulmonary artery, and the aorta. The auricles are relaxed during ventricular systole, and are being filled with blood, which flows into the ventricles as soon as ventricular diastole begins. Then the cycle is repeated.

Although both auricles and ventricles are necessary for the most effective maintenance of the circulation, their functions are not of equal importance. The ventricles, in driving the blood through the pulmonary and systemic vessels, perform the

harder task and may be considered as force pumps. Without the auricles, however, the flow from the great veins would stopped during ventricular systole. Since the auricles are filling during this period there is little delay in the filling of the ventricles during ventricular diastole. The auricles, therefore, may be considered as feed pumps.

Although the rate of the heart beat changes quickly in response to various internal and external stimuli, there is a certain normal rate for each individual. The average normal heart rate for an adult, at rest mentally and physically, is about 72 beats a minute; but for some individuals as low as 50 a minute, or in others as high as 90 would be normal. As a rule, the average heart rate in women is higher than that in men being about 80 beats a minute. The heart beat is most rapid during infancy, being as high as one hundred and forty at birth; but with increasing age it rapidly decreases, until at old age it is only about half that rate. The size of the individual is thought to influence the rate. Tall individuals usually have a slower rate than short persons of the same age. This difference in rate due to size is shown by comparing the mouse and the elephant, the former having a heart rate of about 670, while the heart of the latter beats but 25 times each minute.

The blood vessels. The properties and functions of the blood vessels are in accord with their structure. A typical artery consists of three coats; an internal coat, the tunica intima; a middle coat, the tunica media; and an external coat the tunica adventitia. The tunica intima consists of a structureless elastic basement-membrane lined with elongated flat cells.

The tunica media consists of many layers of circularly arranged plain muscle fibres between which is interwoven a network of elastic fibres. Between the middle and external coats there is an elastic membrane. The tunica adventitia consists of bundles of fibrous and yellow elastic tissues, with scattered longitudinal muscle fibres in its inner layers. In the large arteries the amount of elastic tissue is very abundant, exceeding by far the amount of muscle tissue.

The veins are similar in structure to the arteries in having three corresponding coats, although the amount of elastic and muscle tissue is less, and the amount of fibrous tissue greater than in the arteries of the same size.

The presence of elastic and muscle tissue in the walls of the arteries gives them the properties of elasticity and contractility. The elasticity allows a wide variation in the amount of blood that the arterial system can accommodate. The most important effect of this property of elasticity is to change the intermittent movement of the blood given to it by the heart, to a remittent flow in the arteries, and finally to a continuous flow in the capillaries. With each systole of the left ventricle a greater amount of blood is sent into the arteries than can pass into the capillaries and veins during the time of the contraction; consequently, the walls of the arteries must dilate to balance the pressure of the blood and the elastic reaction of the walls. When systole ends the elastic walls recoil and propel the blood toward the capillaries. Toward the periphery the distention and the recoil diminish, and the intermittency disappears as the blood enters the capillaries.

The property of contractility permits the amount of blood supplied to the tissues in a given time to be regulated. During functional activity the muscle fibres relax and an increased amount of blood is permitted to flow into the tissues to supply the increased need. Upon cessation of activity the muscle fibres contract and diminish the flow of blood. This action takes place mainly in the small arteries and arterioles at the periphery of the arterial system.

The width of the path along which the blood flows varies greatly in its sectional area. Although an individual capillary is microscopic and the aorta is relatively large the total sectional area of the stream bed is greatest in the capillaries and least in the aorta. Since the capillary bed is eight hundred times greater than the aortic bed, and the friction of the blood is increased in passing from the arteries to the capillaries, the velocity of the blood stream is diminished as it passes toward the periphery.

Arterial Blood Pressure

General statement. In the circulatory apparatus the ventricles receive blood through the auricles from the veins. The ventricles send it into the arteries, which are unable to empty themselves immediately through the capillaries. The blood accumulates in the arterial system until the elastic recoil of the distended arterial walls is sufficient to force through the capillaries just as much blood as is ejected into the aorta and pulmonary artery. The cause for the flow of the blood is a difference in pressure between any two points in the circulatory

system. The pressure which is exerted on the sides of the arteries by the flowing blood stream is called the lateral blood diastolic or minimum pressure. The difference between the two pressures is known as the pulse pressure. Half the sum of the maximum and minimum is usually taken as the mean arterial pressure.

The factors determining blood pressure. The blood pressure at a given time in any individual is dependent upon four factors. They may vary independently of one another under normal and pathological conditions; but usually changes in the vasomotor and cardiac nervous systems causing an alteration of one of these factors causes a variance in the others.

(1) An increase in the energy of the heart manifested either by an increase in the rate of the heart or an increase in the volume of blood ejected into the aorta with each beat would tend to cause a rise of blood pressure. But an increase in systolic frequency presupposes a larger amount of blood in the venae cavae in order to raise the pressure. There is a limit to the reserve cardiac energy, and if the peripheral resistance increases beyond a certain point the volume output of the ventricles will decrease. due to the exhaustion of the heart.

(2) Increasing peripheral resistance and rising pressure. or decreasing resistance and falling pressure usually accompany each other unless some equalizing change occurs in the heart.
All blood vessels with the exception of the capillaries contain muscle fibres and are consequently subject to constriction and

dilatation. Under normal conditions the blood vessels have a tonus caused by the equilibrium maintained by the vasoconstrictor and vasodilator nerves. The presence of this tonus in the veins and arteries, by means of which the blood-vascular system is adapted to the blood volume is of great significance. Its disappearance would cause a collection of blood in the veins, and heart failure. The abdominal vessels which are supplied by the splanchnic nerves have the greatest effect upon the general blood pressure through constriction and dilatation.

(3) The elasticity of the arterial walls permitting their extension and recoil with each pulse wave gives a continuous propelling force to the blood. The elasticity varies with the intravascular pressure. With hypertension the distensibility of the arteries is lessened, and the difference between maximum and minimum pressure will be greater than at low pressures. Hardening of the arteries would cause the same effect.

(4) The total blood volume is small as compared with the total capacity of the blood-vascular system. Vasomotor tonus keeps the pressure at a normal point even when haemorrhage or an infusion of saline solution takes place. Losses as large as two-fifths of the original blood volume are said to have very little effect on the mean blood pressure.

Coördination of the heart and vessels by means of nerves. The circulatory system may be considered fundamentally as a mere mechanical hydraulic apparatus, but during life there is a constant adjustment to constantly varying conditions. This adaptability

is a result of the coördination of the heart and blood vessels brought about by the cardiac and vasomotor nervous systems.

The combination of nerves and nerve centers which cooperate to increase or decrease either the rate or force of the heart's contraction may be considered as the nerve mechanism of the heart. There are present in the heart groups of cells, the intracardiac nerve cells, which are in physiologic and anatomic relation with the muscle cells and with the nerves passing to the central organs. Of these latter nerves there are two, the vagus and the sympathetic.

The vagus contains both afferent and efferent nerve fibres. The afferent fibres arise in the ganglia situated on the trunk of the nerve. One branch of each ganglion cell passes to the floor of the fourth ventricle, where it arborizes around the nerve cells; the other branch makes its way along the trunk to the viscera. The efferent fibres arise from the nerve cells situated beneath the floor of the fourth ventricle and make their way to the heart where they arborize around the intracardiac nerve cells.

The sympathetic is efferent in function. The fibres arise in the ganglion stellatum and inferior cervical ganglion and after reaching the heart probably terminate freely on the muscle cells. The nerve cells in the ganglia are in communication with cells beneath the floor of the fourth ventricle by means of fibres passing down the cord and emerging in the anterior roots of the 2d and 3d thoracic nerves. Then by way of the white rami communicantes they pass to the ganglia where they arborize around the cells supplying the sympathetic.

Experiments made largely upon the nerves of the frog and turtle demonstrate the respective action of the two nerves. The vagus has been shown to inhibit the action of the heart, while the sympathetic accelerates and augments its action.

The vagus, which is in communication with the cardio-inhibitory center in the medulla, and the sympathetic which is in communication with the cardio-accelerator center probably located in the medulla as well, exert an antagonistic action on the heart. This action under normal conditions is in equilibrium. The cardio-inhibitor and accelerator centers may be directly stimulated by substances in the blood and lymph, and are probably in a condition of tonic activity as a result. They may also be stimulated from the emotional centers of the brain.

The vasomotor nerves are of two classes, namely, the vasoconstrictors, the stimulation of which causes a contriction of the blood vessels, and the vasodilators, the stimulation of which causes a dilatation of the blood vessels. These fibres terminate in the middle coat of the blood vessels, which consists of plain muscle tissue circularly disposed.

The vasoconstrictor nerves, belonging to the sympathetic nervous system, consist of preganglionic fibres arising in the central nervous system, and postganglionic fibres arising in the cells of some sympathetic ganglion. They are distributed mainly to the skin and abdominal viscera, exerting their action continually to keep the blood vessels of the right calibre to

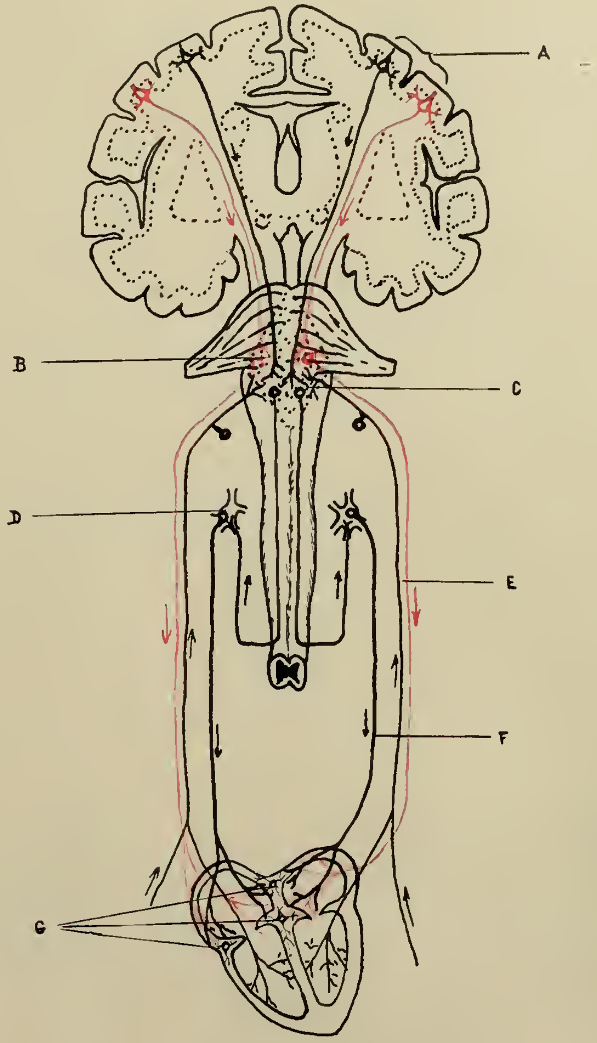

Fig. 2. Diagram of the nerve mechanism of the heart. A. Emotional centers. Exhilarating (black), depressing (red). B. Cardio-inhibitor center. C. Cardio-accelerator center. D. Ganglion stellatum. E. Vagus nerve. Inhibitor (red), sensor (black). F. Sympathetic nerves, accelerator and augmentor. G. Intra-cardiac nerve cells. (From Brubaker)

maintain a sufficient pressure for the flow of the blood. Increased action of these fibres causes a diminution in the size of the vessels in the region of the arterioles, which in turn causes an increase in preipheral resistance and a rise of arterial pressure, and vice versa. The preganglionic vasoconstrictor fibres are in communication with the cells of the vasoconstrictor center in the medulla, which in turn communicate with the cells in the higher centers. A nervous mechanism of this type is obviously susceptible to reflex stimulation through the sensory nerves. This may occur by means of the pressor fibres which when stimulated cause reflex vasoconstriction, or by the depressor fibres which cause reflex diminution of tonus.

The vasodilator fibres form a system somewhat similar to that of the vasoconstrictors, although no definite vasodilator center has been demonstrated and they are not in tonic activity. Their function is relatively of less importance since they are distributed especially to the erectile tissue, glands, bucco-facial region, and muscles. Only by reflex stimulation can they normally affect the blood vessels. Many of the depressor effects are due to reflex stimulation of the dilators.

Methods of Estimating Blood Pressure

Historical. Poiseuille in 1828 introduced the mercurial type of manometer. The determination was made directly from the blood vessels, but the pressure was exerted on a mercury column through the medium of a solution of Na_2CO_3 to prevent coagulation. This is the method which is used to-day wherever it is necessary to make direct determination.

Ludwig in 1847 made the manometer self-registering by the application of the kymographion. This consisted simply of a revolving drum of smoked paper, upon which the oscillations of the mercury in the tube were traced and magnified by means of a lever which was connected by a rod with a pith ball floating on the surface of the mercury. The tracings obtained in this way do not tell a complete story of the blood pressure on account of the inertia of the mercury. The value of the sphygmomanometer at once became evident. Since that time various instruments have been devised for the determination of blood pressure in man.

In 1855 Vierordt suggested a method of indirect measurement by noting the amount of pressure necessary to obliterate the flow of blood in a peripheral artery. This is the fundamental principle in all modern sphygmomanometers.

Until 1876 various unsatisfactory methods were used to measure the counter-pressure necessary to close the lumen of an artery. In this year v. Basch constructed a sphygmomanometer for clinical use, which recorded the amount of pressure in millimeters of mercury. In this instrument a bag containing water was connected directly with the manometer. The bag was pressed on an artery until the pulse could no longer by felt in the artery distal to the compression. This instrument recorded the maximum end-pressure. This was the first time comparatively accurate information about blood pressure could be obtained for clinical use.

Potain in 1889 made use of air instead of a fluid, constructing his manometer on the anaeroid principle with a dial graduated in millimeters of mercury.

Although the instruments of v. Basch and Potain marked progress in the determination of arterial pressure in man and undoubtedly stimulated research in this important field, yet the results obtained were far from satisfactory because of the method of application. In using these instruments pressure had to be applied to an artery against a bone. The depth of the artery below the surface, the amount of tissue surrounding it, and the size of the artery were factors which caused a considerable error.

About the time that v. Basch was perfecting his instrument Marey was working on a new principle. He made observations on the effect of applying pressure equally to all sides of the vessel instead of to a single surface. For this purpose he constructed a tight box in which the forearm could be inserted. The box was connected with a movable reservoir of water by which the pressure within would be regulated. The apparatus was connected with a mercury manometer and a recording tambour. As the pressure was raised the amplitude of the pulse waves transmitted through the fluid was increased to a certain point and then decreased. By this time the skin was blanched showing that the maximum pressure was overcome. Marey concluded that when the pulsations reached the maximum, the extravascular pressure was just equal to the intravascular, and the walls of the vessels having no pressure from either side would oscillate with maximum amplitude. Subsequent investigation has shown that this is an accurate criterion

for the measurement of minimum pressure. The first instrument of Marey was later much elaborated by Hürthle.

In a second apparatus Marey used one finger instead of the whole forearm. This method gave unsatisfactory results. In 1895 Mosso used the same principle and constructed an instrument for laboratory use. Gärtner, by means of his tonometer estimated the maximum arterial pressure by measuring the force just necessary to keep the digital arteries occluded. Estimations of this kind are unreliable, for the small digital arteries are subject to great local vasomotor changes.

None of the sphygmomanometers introduced prior to 1896 complied with all the essential requirements for general use by physicians, such as reasonable accuracy, freedom from subjective errors, ease of application, and portability.

The Hill-Barnard and Riva-Rocci sphygmomanometers embody the principle of compression of the artery from all sides by means of a hollow rubber band which encircles the arm of a subject. This band is connected, by means of tubes containing air, with a bulb for increasing the air pressure and a manometer to record it. The Hill-Barnard instrument has a metal manometer and is used for the determination of minimum pressure. The Riva-Rocci apparatus has a mercury column and measures maximum pressure.

Modern methods. The method of estimating the tension of the pulse by compressing an artery with the fingers is very common in clinical work. Janeway calls it an extremely fallacious

and time-honored method, the error of which will soon be shown by the use of the sphygmomanometer. In this method an attempt is made to estimate the maximum end pressure in an artery by compressing it with the finger until the pulse cannot be felt by a second finger distal to the compression. In the palpatory method the subjective element is a great source of error. The muscular sense only judges the total of the force exerted. Since the amount of pressure exerted on a fluid is proportional to the area compressed, it is evident that in large arteries the blood pressure will seem greater than in small ones. The amount of tissue compressed and its relation to the artery will also introduce error. This brief consideration shows that this method can never be more than an approximation, liable to error even with skilled observers.

A sphygmomanometer for the graphic determination of blood pressure, which combines the principles of the Riva-Rocci and Hill-Barnard instruments, was designed by Erlanger in 1904. This instrument practically eliminates the subjective element from determinations, measuring both maximum and minimum pressures.

The essential parts and construction of this apparatus are as follows. A hollow rubber cuff, which is fastened around the upper arm by means of a strap, is in direct communication with a mercury manometer, a bulb for raising the air pressure in the instrument, and a rubber bag contained in a glass chamber. The chamber communicates with a tambour; and a lever traces the oscillations on a revolving drum. A stop-cock, between the pressure bulb and the rest of the apparatus, must be opened while the pressure is being raised within, and may then be turned

to either a fine capillary opening or a large one, by means of which the pressure is lowered more or less slowly.

In order to measure the maximum pressure the air pressure in the apparatus is raised until the pulse disappears in the artery distal to the compression. By manipulating the stop-cock the pressure is allowed to fall slowly. The lever will be depressed and its oscillations will gradually increase. When the extravascular pressure falls below the maximum intravascular pressure a sudden increase in the amplitude of the oscillations is noticed. A change in the direction of the trough line, and a change in the form of the pulse wave, as well, takes place. At this point the maximum pressure is read from the manometer

Minimum pressure may be determined by continuing the above procedure. The wave amplitude will continually increase with falling pressure until the extravascular and intravascular pressures are equal. Then a sudden decrease in amplitude takes place. At this point the minimum blood pressure is read. Or, by the proper manipulation of the stop-cock, the pressure is allowed to fall five millimeters at a time, and a tracing is obtained at each step. The pressure at which waves of maximum amplitude are obtained is the minimum blood pressure.

A method of determining the return of the pulse wave under compression by auscultation was first demonstrated by Korotkow (1905), in St. Petersburg. Any sphygmomanometer may be used which involves the principle of obliterating the flow of blood in an artery. A point over the artery from two to four centimeters

below the cuff is selected for auscultation. The pressure in the sphygmomanometer is raised above the maximum blood pressure and then allowed to fall slowly. When the first pulse wave breaks through the constriction under the cuff a distinct sould is heard. The maximum pressure is read at this time.

A series of sounds follow which may be divided into five phases. At the fourth phase there is a dulling of the tone. By comparing the auscultatory phenomenon with the tracing of the Erlanger Sphygmomanometer, Dr. Arthur W. Weysse and I have demonstrated that the minimum blood pressure should be read at this phase.

The auscultatory method is the most convenient and accurate means of determining the blood pressure. It is fast being adopted wherever it is necessary for a quick, easy, and accurate blood pressure determination to be made.

Variations in Blood Pressure in Normal Individuals.

In different individuals. Blood pressure in different persons will vary to a great degree according to age, sex, and occupation. Temperament undoubtedly has an influence, while it is probably that the size of the individual has little effect. Janeway found that the maximum pressure in young male adults ranges between 80 and 160 mm. of Hg from purely physiological causes. In women the maximum pressure may have the same range, but the pressure is usually 10 mm. of Hg less. In old age, which is usually accompanied by increased peripheral resistance, the same

author gives the range of maximum pressure from 140 to 160 mm. of Hg. Cook and Briggs say that in children under two years a maximum pressure of from 75 to 90 mm. of Hg is found; while during early childhood the range of maximum pressure is from 90 to 110 mm. of Hg.

In the same individual. The blood pressure at any given time depends upon the inter-relation of cardiac energy, peripheral resistance, extensibility of the arterial walls, and the volume of circulating blood. Of these factors the first two, governed by the cardiac and vasomotor centers in the medulla oblongata, are most variable. It would seem that these four more or less variable factors would be capable of balancing any changes in blood pressure, and tend to keep it fairly constant. This is true to a certain degree, but the arterial pressure varies from time to time in the same individual.

A typical blood pressure tracing shows three sets of periodic variations, the first, short rhythmical pulse waves, the second, longer respiratory waves due to inspiration and expiration, and the third, the so-called Traube-Herring waves embracing several respiratory waves.

Various physical and mental states influence the blood pressure during the day. Muscular exercise, change of posture, the ingestion and digestion of food, mental effort, and sleep, have an effect upon the pressure. In Part II the effect of some of the above factors has been studied.

The Practical Value of a Knowledge of the Blood Pressure and Pulse Rate.

The maximum pressure, determined in the brachial artery by graphic or by the auscultatory method, is a close approximation to the maximum lateral pressure in the aorta. Theoretically, there seems to be no reason why the minimum pressure in the large arteries, at a given time, should vary to any great extent. A knowledge of the maximum and minimum pressures in the brachial artery enables us to judge pretty accurately of the maximum and minimum pressures in the aorta. The value that a knowledge of the pressures has on the interpretation of the circulatory phenomenon is discussed by Erlanger and Hooker (1904), and a brief review of the discussion is presented in this section.

Although it is generally believed that a knowledge of the mean arterial pressure would be more valuable than a knowledge of either the maximum or the minimum pressure, Erlanger and Hooker question the idea. They show that the arithmetical mean of the maximum and minimum pressures is not the true mean blood pressure, but that the true mean lies nearer the minimum than the maximum pressure. Moreover, they believe that the mean follows the minimum pressure more closely than it does the maximum. In general, a knowledge of the minimum is sufficient to judge of the mean.

Erlanger and Hooker recognize, however, that a knowledge of any one of the pressures is not sufficient for clinical purposes, and believe with Hensen that there is far greater value in knowing the amount of blood that an organ receives in a given time than in knowing the pressure under which the organ receives the

blood. These authors show theoretically that a simultaneous determination of the maximum and minimum pressures and the pulse rate will give this information.

The height of the pulse pressure in the aorta depends upon the amount of blood forced into it during systole. When the mean blood pressure is constant an amount of blood equal to that thrown into the arteries during systole must pass into the veins during diastole. Therefore, a knowledge of the pulse pressure, (the difference between the maximum and minimum pressures) and the duration of either diastole or systole would permit, within certain limits, an estimation of the velocity of the blood flow. Since the duration of systole is so short (.06 sec.) its variations would be little; and when we consider the relatively crude methods of estimating blood pressure in man, it would seem that a knowledge of the pulse rate and pulse pressure would give a fairly accurate estimate of the velocity of the blood flow. The pulse pressure depends approximately on the amount of blood that passes out of the arteries during one cardiac cycle; and the amount of blood that escapes will vary directly as the pulse rate. Within certain limits, therefore, the velocity of the blood flow varies directly as the product of the pulse pressure and pulse rate. (P.P. x P. R.)

In order to know the absolute velocity of the blood flow it would be necessary to consider the rate of systolic output, the rate of flow from the arteries into the veins, the distensibility of human arteries at different pressures, and the amount of blood in the systemic arteries under various conditions.

Erlanger and Hooker believe that the value of any one of these factors would not be so great as to cause serious error, and conclude that a knowledge of the maximum and minimum pressures permits the estimation of the relative velocity of the blood flow.

PART II.

Observations on Diurnal Variations in Blood Pressure.

General statement. The purpose of this investigation was to make a study of the normal variations of the maximum, minimum, and pulse pressures, pulse rate, and the relative velocity of the blood during the day. Although the question of diurnal blood pressure is an important one, most of the investigations in this field have been incomplete, since the maximum pressure alone has been studied, and inconclusive, since the number of subjects studied has been too few.

In this paper I present the results of a series of observations on diurnal blood pressure in a group of healthy young men, all of about the same age, and all living under the same conditions during the period of observation. Incidentally, the effect of the ingestion and digestion of meals was demonstrated.

A Brief Review of the Literature.

Zadek (1881) made determinations with the v. Basch Sphygmomanometer (which measures the maximum pressure) on three normal individuals. The observations were taken three times a day, that is, morning, afternoon, and evening, for periods of from three to nine successive days. He found that an average rise of from 8 to 15 mm. of Hg occurred in the afternoon, and believed it to be entirely independent of the mid-day meal, which he observed caused a rise of from 10 to 20 mm. of Hg. Toward night the pressure fell again though it was still higher than in the morning. He found that the pulse rate varied inversely with the blood pressure.

v. Maximowitsch and Rieder (1890) made determinations with a v. Basch anaeroid sphygmomanometer on a few normal and pathological subjects to study the effects of liquids and muscular work upon the blood pressure. They found that when 1/2 liter of water was taken a slight rise of pressure occurred followed by a gradual return to the original after 40 to 50 minutes. When greater quantities were taken, that is, 1 to 2 liters, drunk in 20 to 40 minutes, the return to normal did not occur until 1 to 2 hours later. Beer caused a more marked rise than water. One liter drunk within 5 minutes caused a rise of from 20 to 25 mm. of Hg, attaining its maximum in 50 minutes, and returning to the original in 1 1/2 hours. When greater quantities of beer were taken the rise remained from 2 to 2 1/2 hours. The drinking of water, as well as beer and other alcoholic liquors, caused an increase in the pulse rate.

Howell (1897), while studying the relation of sleep to blood pressure, by means of a plethysmograph, found that although there was a fall of pressure with onset of sleep, a gradual rise took place soon after, until, on awakening, the pressure was the same as before sleep occurred.

Hill (1898), while investigating by means of a Hill-Barnard sphygmomanometer the changes in the circulation caused by rest, sleep, and work, found the pressure as low when the subject was lying awake in bed in the morning as when lying in bed at night. Observations which he made hourly during the day upon himself show that his pressure was higher after a hard day's work than in

the morning. He does not consider the effect of the meals upon the arterial pressure.

Colombo (1899), using a Mosso sphygmomanometer, as well as that of v. Basch, reported observations on one normal individual, although he mentioned having examined different persons. He determined the diurnal curve under two different sets of conditions. First, meals, muscular exercise, and sleep were so arranged that they had no effect on the observations. This was done by changing the time of meals and waiting until their effects had presumably passed off before observations were taken, by refraining from muscular activity, and by changing the period of sleep. By taking observations during parts of several successive days a theoretical diurnal curve was made for one day. Second, meals, muscular exercise, and sleep were taken at the regular hours. The theoretical curve made with the Mosso sphygmomanometer, by means of the criterion of maximum oscillations, shows that during the hours when digestion would ordinarily have taken place a fall of pressure occurred, although nothing had been eaten. During the morning hours before daybreak there was a rise of pressure, although the subject was awake. During the warm hours of the day, from 2 to 4 p. m., the pressure was lower than during the cool hours of the forenoon, although the temperature of the laboratory did not change. The curve obtained with the v. Basch instrument, from the temporal artery by means of the criterion of the disappearance of the pulse palpated distal to the compression, showed changes in the pressure exactly the reverse of those obtained in the

former case. When the Mosso apparatus was used with the criterion of the disappearance of the pulse, changes similar to those obtained with the v. Basch instrument were observed. When meals were taken, the Mosso apparatus used with the criterion of maximum oscillations, showed a fall in the blood pressure, averaging 20 mm. of Hg, taking place immediately and attaining its lowest point 2 1/2 hours later. This occurred whether there was a rise or a fall in the theoretical diurnal curve. The v. Basch instrument showed an elevation of pressure lasting 4 hours immediately after meals. An increase in the pulse rate, respiration, and body temperature, also occurred after meals. Not recognizing that the Mosso apparatus as ordinarily used measures the minimum pressure, while the v. Basch instrument measures the maximum pressure, Colombo attempted to reconcile these apparently conflicting results by attributing the rise shown by the v. Basch apparatus, when applied superficially to the temporal artery, to the great vasodilatation which takes place after meals. Because he believed the Mosso apparatus more sensitive, he regarded the results obtained with it as the more accurate.

Weiss (1900) reported observations, taken with Gärtner's tonometer, on a normal individual. Thirteen readings were taken at intervals from 9 a. m. to 12 midnight on one day. After the morning and noon meals a marked fall in blood pressure occurred, while a rise took place after the evening meal. The final reading at night was 20mm. of Hg higher than the first reading taken in the morning.

Hensen (1900) made determinations with a Riva-Rocci sphyg-

momanometer on a healthy girl who remained in bed for nineteen days. The observations were made twice a day, at 7 a. m. and 9 p. m. He found the evening readings from 5 to 15 mm. of Hg higher than the morning pressures. His chart shows that the pulse rate varied directly with the maximum pressure. Hensen believed, with Zadek, that there is a periodic afternoon rise independent of meals.

Brief reference may be made to Gumprecht (1900) who reported that he usually found a fall in pressure of 10 to 15 mm. of Hg in the forenoon, while the chief meal of the day generally caused a rise of about 20mm. of Hg. He made the determinations with a Riva-Rocci sphygmomanometer.

Jellinek (1900) reported determinations made with Gärtner's tonometer, on two healthy soldiers for a period of 10 days, during which time they did only light sentry duty. The observations were taken six times a day, 5 a. m., 6 a. m., 11 a. m., 1 p. m., 5 p. m., and 8 p. m. He found the readings highest immediately after the noon meal, and during the digestive period. The pressure was almost as high before the subject went to bed as in the morning. The pulse rate was not reported. He also made observations on twenty soldiers before and after meals, which consisted of soup, meat, vegetables, and bread. Of these subjects, 14 showed a rise in pressure, 2 a fall, and 4 no change. The pulse rate increased in every case except one, in which a fall of blood pressure occurred and no change in the pulse rate. Jellinek concludes that the blood pressure is highest during the afternoon hours.

Brush and Fayerweather (1901) studied the changes which occur in blood pressure during the period of normal sleep. The obser-

vations were made with a hand plethysmograph used with the criterion of maximum oscillations. During the period of sleep the blood pressure in the wrist arteries fell for the first few hours, after which, a gradual rise took place, broken by long waves. Finally, on awakening in the morning, the blood pressure was greater than before going to sleep in the late evening.

Brief mention may be made of Hayaski (1901), and Sommerfeld (1901), who found a rise of blood pressure after the midday meal.

Cook (1903) reported a rise of from 5 to 10mm. of Hg in the maximum blood pressure of infants after feeding.

Goldwater (1903), using Gärtner's tonometer, determined the blood pressure of a healthy medical student. He took readings nine times, from 9 a. m. to 10 p. m. during one day. The curve shows a continuous rise from 9 a. m. to 4 p. m., a slight fall from 4 p. m. to 6 p. m., and a marked rise after the evening meal until 10 p. m. On the next morning the pressure was the same as on the previous morning. He believed that there was a periodic rise in the afternoon which was independent of the midday meal. The fall of blood pressure, during the digestive period noted by Weiss (1900), who used Gärtner's tonometer, was not confirmed by Goldwater.

Oliver (1903) published a chart of the arterial blood pressure, taken with his haemodynamometer every hour from 8.30 a. m. to 10.30 p. m. Although the haemodynamometer records the maximum oscillations he supposed it to measure the mean arterial pressure. A rise of blood pressure, averaging from 15 to 20 mm. of Hg,

took place after meals, attaining its maximum in about 1 hour, and lasting from 2 1/2 to 4 hours. The pressure at 10.30 p. m. was lower than at 8.30 a. m.

Karrenstein (1903), working with Gärtner's tonometer on soldiers, found a rise of from 10 to 20 mm. of Hg after the principal meal. There was always a rise of from 10 to 25 mm. of Hg after two or more liters of beer were drunk.

Janeway (1904) published a chart of the diurnal variations which he observed with the Janeway sphygmomanometer. He believes the curve to be a composite record of the effects of the various physical and mental states on the blood pressure. The chart shows a rise in maximum pressure on bathing and dressing in the morning, a fall after breakfast, a rise after the noon meal, a slight fall before the evening meal, a rise after it, and a fall before going to bed. The minimum pressure usually followed the maximum, except after the noon and evening meals, when it fell. Janeway is inclined to believe that the maximum and minimum pressures are unequally affected by the taking in of food.

Erlanger and Hooker (1904), in a study of blood pressure and pulse pressure, describe five experiments on an albuminuric patient which show variations in the maximun, minimum, and mean blood pressures, pulse pressure, pulse rate, and the product of the pulse pressure and pulse rate. In each of the experiments the Erlanger sphygmomanometer was used and three readings made at each determination. In Experiment 1. determinations were made every half hour from 7.35 a. m. to 10.30 p. m., Experiment 2. every

half hour from 8 a. m. to 10 p. m., Experiment 3. every 10 minutes from 9 a. m. to 2 p. m., Experiment 60. every few minutes from 9.15 a. m. to 5.55 p. m., Experiment 65, every few minutes from 9.45 a. m. to 4.15 p. m.

Erlanger and Hooker believe it possible to explain the diurnal variations almost entirely by the effect of the ingestion of meals. Experiments 1, 2, 60, and 65, bring out the fact that variations in pulse pressure occurred in the form of waves corresponding to the ingestion of meals. As a rule, there was an increase in the pulse pressure a few minutes after the ingestion of food, which reached its maximum in one to two hours, and then declined more slowly, not wholly coming back to the level before the meal.

Experiments 2, 60, and 65. show that when the pulse pressure reached its minimum it tended to increase very gradually until the next meal. There was a gradual increase in pulse pressure throughout the day, upon which were built the wave-like increases that followed the ingestion meals. There seemed to be no relation between the amount of food ingested and the increase in the pulse pressure. The increase after luncheon was greatest although there was no more food taken than at breakfast. The greatest amount of food was eaten at the evening meal but the increase in pressure was not as great as at luncheon. The maximum and minimum pressures tended to separate when food was taken; and, as a rule, the rise of the maximum pressure was greater than the fall of the minimum, but not infrequently the reverse occurred.

The mean blood pressure usually increased with the ingestion of meals, but often there was little or no change.

Experiments 2, 3, 60, and 65, show that the pulse was accelerated with the pulse pressure. The product of the pulse pressure and the pulse rate (P. P. x P. R.) followed the pulse pressure curve. An increase in the velocity of the blood flow probably took place with the functional activity of the digestive organs.

Erlanger and Hooker believe that throughout the day the velocity of the blood flow increases, but that the gradual increase is partly obscured by waves of velocity changes induced by the ingestion of food. They attribute the gradual increase in the velocity of the blood flow to the cumulative effect of the repeated ingestion of meals on digestion and metabolism.

Brooks and Carrol (1912), in a clinical investigation of the effects of sleep and rest on blood pressure, studied a large number of pathological cases with the sphygmomanometers of Sahli, and Janeway, measuring only the maximum pressure. They considered the subjects in three groups, the first, that of medium pressure, the second, low pressure, and the third, high pressure. Sixty-eight patients had an average afternoon pressure of 142 mm. of Hg. Two hours after the onset of sleep the pressure showed an average drop of 24 mm. of Hg· and three hours after awakening in the morning there was still a depression of 12 mm. of Hg. Thirty patients had an afternoon pressure of 100 mm. of Hg. Two hours after the onset of sleep the pressure showed an average drop of 16.5 mm. of Hg· and three hours after the

morning awakening there was still an average depression of 6.6 mm. of Hg. Twenty-nine patients had an afternoon pressure of 204 mm. of Hg. Two hours after the onset of sleep the pressure showed an average fall of 44.8 mm. of Hg; and three hours after awakening in the morning, there was still an average depression of 22.8 mm. of Hg. The effect of food taken during the period of observation is not considered.

Loeper (1912) reports the determinations made, with Pachon's sphygmomanometer before and after a meal, on three normal individuals. In each case there was a primary rise, occurring from 15 to 45 minutes after the meal, followed by a fall below the original. A second rise higher than the first occurred within three hours. He believes the first rise to be due to the distention of the stomach, and to be proportional to the amount of food taken. The first fall coincided with the period of gastric secretion, being more marked when irritating foods were taken. The second rise corresponded to the filling and distention of the intestine.

Faught (1915) published a chart of the variations of the maximum blood pressure during the working hours of a healthy young man. It shows that a rise in pressure took place after each meal, and a general rise during the day.

Subjects, Apparatus, and Method of Procedure.

In this investigation ten healthy students were used as subjects. They were all between nineteen and twenty-five years of age.

A Faught pocket sphygmomanometer was used, and the phases were distinguished with a Bowles sphygmometroscope.

All the determinations were made on the right arm of the subject, who was seated, so that the cuff or the sphygmomanometer was approximately on the level of the heart. The maximum pressure was read at the onset of the 1st phase; the minimum pressure was recorded at the onset of the 4th phase. The final readings that were recorded for each determination are the means of three trials for each pressure. The pulse rate was determined at the wrist.

In order to accustom the subjects to the method of procedure and to insure normal readings a preliminary period of observation on each subject was begun at 4.30 p. m. of the first day. Determinations were made at 5 p. m., 6 p. m., which was just before dinner, 6.45 p. m. which was just after the meal, 7 p. m., and every half hour until 9.30 p. m., which was just before the subject retired. The main period of observation continued throughout the whole of the following day. Determinations were made at 7.30 a. m. while the subject was seated in bed, 8 a. m., which was just before breakfast, 8.30 a. m., which was immediately after the meal, 9 a. m., which was after a ten minute walk to the college, and every hour between classes until 12 noon, when a determination was made just before luncheon. Observations were made at 12.30 p. m. immediately after the meal, 1 p. m., and hourly until 6 p. m., when determinations were made at the same intervals as on the previous evening until 9 p. m.

The students did the usual amount of study and class room work during the period of observation.

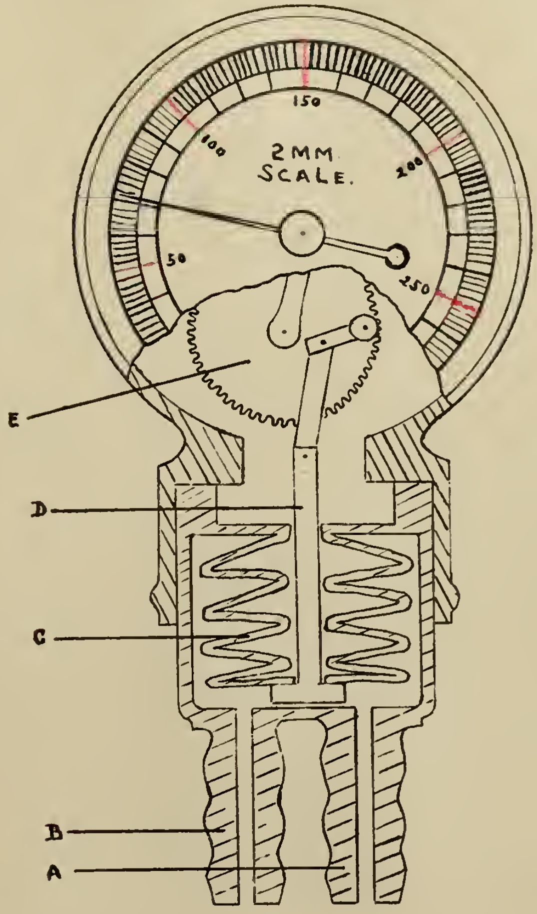
150
100
2MM
SCALE.
200
50
250
E
D
C
B
A

Fig. 3. Diagram of the Faught sphygmomanometer with part of the exterior removed, showing the internal mechanism. A, B. Nipples for the attachment of tubes. C. Metal wall of the compression chamber. D. Rod. E. Gear mechanism.
(From a pamphlet published by George P. Pilling & Son Co.)

The morning meal consisted of fruit, cereal, toast, and coffee. Luncheon was a little larger, consisting of a stew, or chowder, with bread, cocoa or milk, and dessert. The evening meal was the largest, consisting of soup, roast meat, potatoes, other vegetables, bread, tea, and dessert.

Detailed records of the mental and physical activities of the subjects were kept.

Results.

The conditions under which the observations were taken were so uniform that an average or typical diurnal blood pressure curve could be made from the diurnal curves of the ten subjects.

The mean average maximum blood pressure, obtained by taking a mean of the average pressures of the curve, is 120 mm. of Hg; the mean average minimum is 85 mm. of Hg· which gives a mean average pulse pressure of 35 mm. of Hg; while the mean average pulse rate is 72 per minute.

An examination of the typical diurnal blood pressure curve brings out two important points: first, the variations in maximum blood pressure, pulse pressure, and pulse rate, are very regular, and correspond to the periods of ingestion and digestion of food; second, minimum blood pressure is exceedingly uniform throughout the day, there being no regular waves corresponding to meals.

The typical maximum blood pressure curve shows, after each meal, an average rise of 8 mm. of Hg above the pressure previous to the meal. After the 40 meals taken by 10 different individuals, there was a rise in 38 cases; while in 2 cases there was no change. The amount of food taken, or the time of day did not seem to have

any effect upon the height of the rise. The rise after dinner was no higher than that after luncheon, and but 1 mm. of Hg higher than that after breakfast, although the evening meal was largest. An average of 2 1/2 hours elapsed before the pressure returned to its former level before the meal; while after luncheon the pressure did not return to the same low level as before the meal.

On comparing the variations with the mean average maximum pressure of 120 mm. of Hg it was found that the average elevation caused by meals was only about 5 mm. of Hg at the most, which lasted but one hour before it fell gradually below the mean level. The fall continued until the beginning of the next meal. The general level of the maximum blood pressure showed a slight increase in elevation throughout the day.

After 40 meals taken by 10 different individuals there was a slight rise of the minimum blood pressure in 19 cases, a slight fall in 18 cases, while in 3 cases no change took place. The typical diurnal minimum blood pressure curve is entirely free from wave-like variations. In the morning the level of the minimum was a few millimeters above the mean average level of 85 mm. of Hg. A gradual fall took place, reaching its lowest point, 4 mm. of Hg below the mean average level, at 2 p. m. Then a gradual rise occurred corresponding to the fall in the forenoon, until the pressure neared the early morning level. The general level of the minimum pressure tended to become lower throughout the day.

The pulse pressure curve showed, consequently, the same wave-like variations corresponding to digestion, as the maximum.

There was a tendency for the pulse pressure to increase throughout the day, due to the general separation of the maximum and minimum pressures.

After 40 meals taken by 10 different individuals there was an increase in the pulse rate in 31 cases, a slight decrease in 5 cases, and no change in 4 cases. The typical pulse rate curve showed wave-like variations, similar to those of the maximum and pulse pressures, occurring with the periods of digestion. No other waves were present. An average increase of 10 beats per minute, above the rate previous to the meal, occurred after the meal. The increase at breakfast was most marked, probably due to the effect of the coffee taken. Because the elevation after the noon meal did not wholly fall to the former low level before the evening meal, the increase in pulse rate was not as marked at dinner, although the actual value of the pulse rate was above the value of the pulse rate after luncheon. The increase in pulse rate after each meal did not seem to be proportional to the amount of food eaten, since the height of the rise after breakfast, and after luncheon as well, was almost twice as great as that at the evening meal, although the former two meals were much smaller than dinner.

As might be expected, the velocity of the blood flow (P.R. x P.P.) increased after each meal. After luncheon it did not return to the former level before the meal. There was, consequently, a gradual increase in the velocity of the blood flow throughout the day.

The results of this investigation confirm, in general, the

work of Erlanger and Hooker (1904). It seems that there is no tendency for any regular diurnal variations other than the elevations in maximum pressure, pulse pressure, and pulse rate. The typical curve, however, shows that the variations attained their maximum sooner than reported by Erlanger and Hooker. The maximum pressure is generally at its highest point immediately after the meal, and remains at the same level for approximately half an hour. The pulse pressure, pulse rate, and velocity of the blood flow, are increased immediately on the ingestion of food, but do not reach their maximum until about half an hour later, after which they gradually decrease, and, except after the morning meal do not fall to the former level before the meal. There is, consequently, a gradual increase during the day. Whether this gradual increase is due wholly to the cumulative effect of the repeated ingestion of meals on digestion and metabolism, as Erlanger and Hooker suggest, or whether the general increase in physical and psychical activities that occur during the day has some effect, I am not prepared to state. It is evident that the ingestion and the digestion of meals are the most important factors causing the diurnal variations in blood pressure. It seems that these variations are great enough and constant enough to be considered whenever blood pressure determinations are made.

The fall of blood pressure after the primary rise, followed by the secondary rise, noted by Loeper (1912) is not confirmed by this investigation, although determinations were made, after breakfast and luncheon, at intervals of half an hour, and after dinner a second determination was made 15 minutes after the first

THE AVERAGE DIURNAL BLOOD PRESSURE RECORD OF THE TEN SUBJECTS.

Time p. m.	Maximum mm. Hg	Minimum mm. Hg	Mean mm. Hg	Pulse Pressure mm. Hg	Pulse Rate	PP x PR.	Notes.
4.30	119.5	84.1	101.8	35.4	72.0	2549	
5.00	117.7	83.5	100.6	34.2	71.1	2432	
6.00	118.0	84.0	101.0	34.0	74.9	2547	Before dinner
6.45	127.2	88.2	107.7	39.0	78.1	3046	After "
7.00	124.7	87.7	106.2	37.0	76.0	2812	
7.30	122.0	83.4	102.7	38.6	76.0	2934	
8.00	122.4	85.5	103.4	36.9	71.2	2527	
8.30	120.0	85.0	102.5	35.0	69.7	2439	
9.00	120.5	84.7	102.5	35.8	65.2	2334	
9.30	118.2	84.4	101.6	33.8	64.4	2177	
a. m.							
7.30	118.4	87.6	103.0	30.8	70.3	2165	
8.00	116.4	86.4	101.4	30.0	69.8	2094	Before breakfast
8.30	124.2	85.4	104.8	38.8	79.4	3081	After "
9.00	123.8	84.4	104.1	39.4	84.1	3313	
10.00	118.2	83.6	100.9	34.6	70.7	2446	
11.00	116.2	84.8	100.5	31.4	67.7	2126	
12.00	114.4	83.2	98.8	31.2	66.2	2065	Before luncheon
p. m. 12.30	122.8	83.2	103.0	39.6	70.9	2808	After "
1.00	122.3	82.0	102.1	40.3	79.7	3212	
2.00	118.4	81.4	99.9	37.0	77.6	2871	
3.00	118.8	82.6	100.7	36.2	75.1	2719	
4.00	115.8	82.0	98.9	33.8	71.9	2420	
5.00	117.2	83.4	100.3	33.8	69.6	2352	
6.00	117.4	84.4	100.9	33.0	72.8	2402	Before dinner
6.45	124.6	83.1	103.8	41.5	80.4	3337	After "
7.00	125.2	84.2	104.7	41.0	76.1	3120	
7.30	122.0	84.0	103.0	38.0	73.7	2801	
8.00	119.6	85.0	102.3	34.6	72.3	2502	
8.30	119.7	84.0	101.3	34.7	69.0	2394	
9.00	120.0	86.2	103.1	33.8	68.0	2298	

MEAN AVERAGE

120.0	85.0	102.5	35.0	72.0	2550	

after-dinner observation, and then every half hour.

Conclusions.

1. A rise of maximum pressure, averaging 8 mm. of Hg, occurs immediately on the ingestion of food. A gradual fall then takes place until the beginning of the next meal. These waves seem to be built superficially on a slight general rise of maximum pressure during the day.
2. The minimum blood pressure is very uniform throughout the day, and is little affected by the ingestion and digestion of meals. When it is affected a rise or a fall may take place. There is a tendency for a slight general lowering of the minimum pressure throughout the day.
3. Pulse pressure, pulse rate, and the velocity of the blood flow are increased immediately upon the ingestion of meals. They attain the maximum in half an hour, then decline slowly until the next meal. There is a general increase in each throughout the day.
4. The ingestion and digestion of food cause constant diurnal variations great enough to be considered in blood pressure determinations in practical medicine and in the laboratory.

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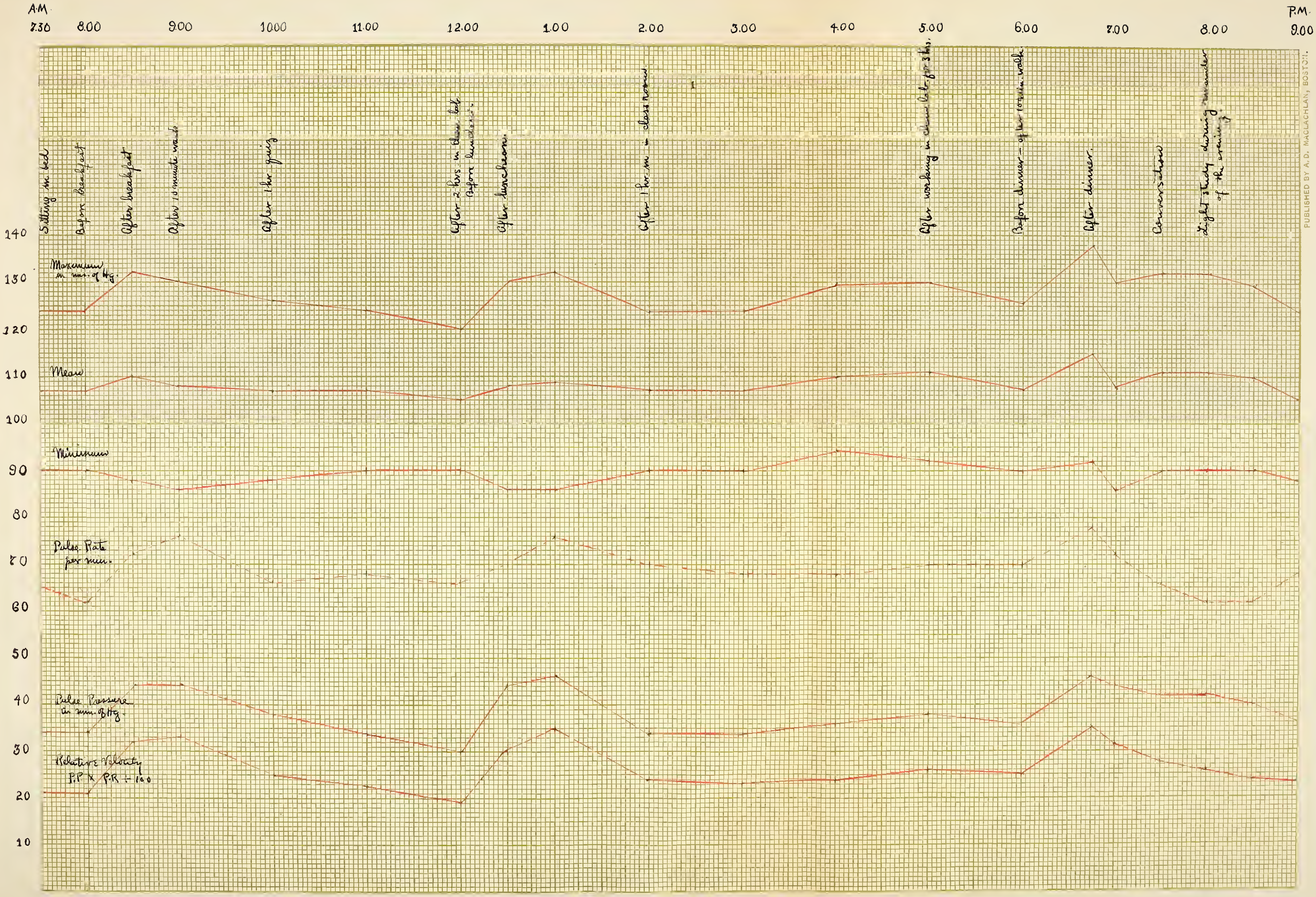

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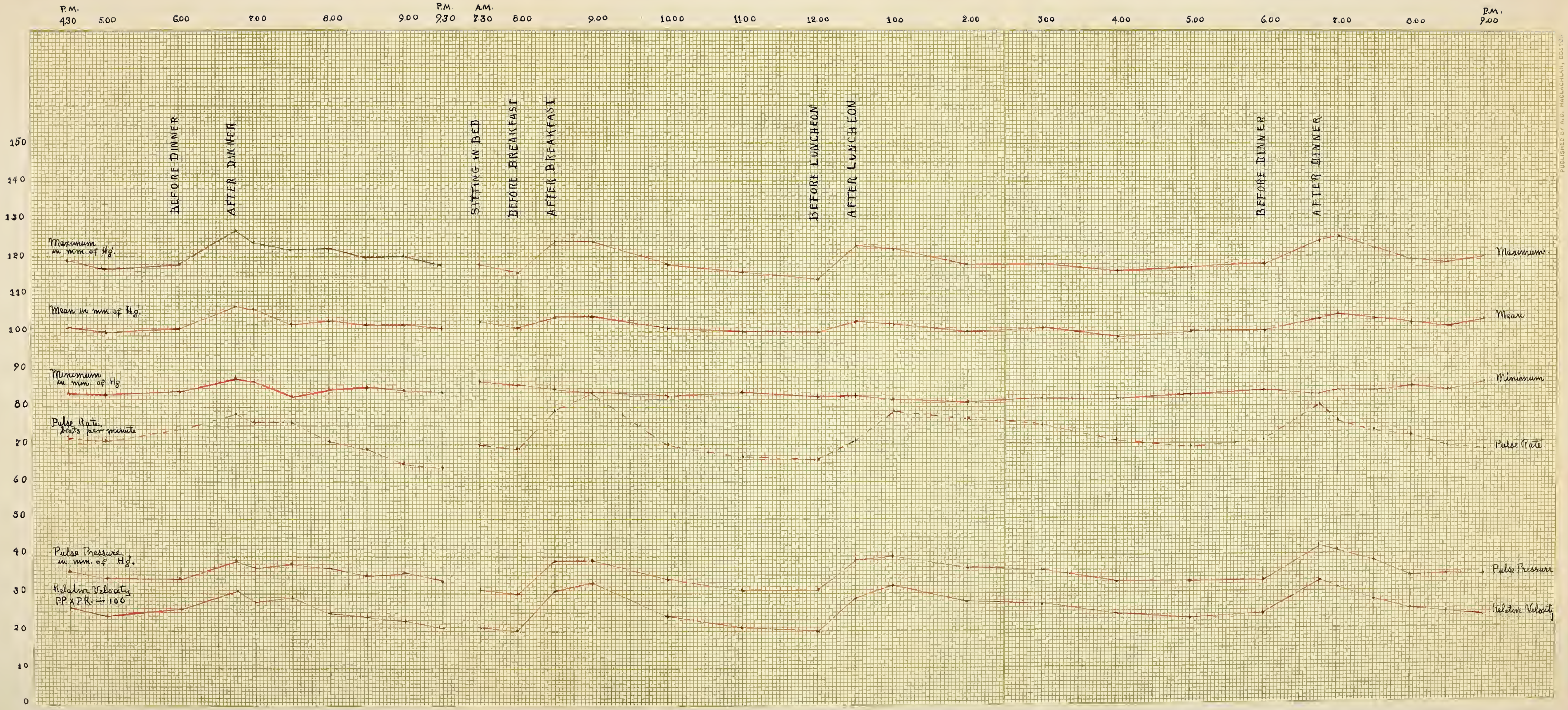
The Durnal Blood Pressure Record of One of the Subjects.



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Preliminary Period of Observation.

The Average Diurnal Blood Pressure Curve of Ten Subjects.

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